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Influence of Testing Procedure on the Shrinkage of a High-Strength Concrete

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Abstract

Concrete shrinkage is both a simple phenomenon in regard to its manifestations – a reduction of apparent concrete volume – as well as a complex one when its causes are to be understood. As a consequence, the depiction of this phenomenon by means of tests generates behavioral doubts as to their results, as there is no single way of representing it. There are basically two ways of representing drying shrinkage: with and without immersion in the first 28 days after casting, stripping and test specimen curing. This study aims to evaluate the effects caused in drying shrinkage by the immersion cure of high-strength concrete (HSC) in a saturated solution of water and lime as referred to in ASTM C157, and for the same high-strength concrete mixture performed without solution immersion. The purpose is to compare both test results and study their applicability and restrictions.
Finally, a further aim is to verify how the procedures for measuring shrinkage strains may influence the results, since mechanical reading equipment was used with of pins set into the test specimens, as well as an electrical Carlson strain meters.
These investigations are part of a future evaluation of test procedures designed and performed by the Concrete Laboratory of Furnas Centrais Elétricas S.A, based in the state of Goiás, Brazil, which may become the focus of a future change in the Mercosul Standard - NM131 and therefore an improvement of the test and its possible interpretations.

Keywords: Autogenous Shrinkage; Drying Shrinkage; High-Strength Concrete; Tests.

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1 INTRODUCTION

Despite the great achievements in the research of creep and shrinkage, the associated phenomena are still far from being comprehended, even considering that outstanding researchers in the field of cement and concrete have been involved with this theme [1]. One way of understanding these concrete phenomena is by means of tests whose representations of the behavior of a certain property in situ is hardly accurate, due to limitations in the test specimen volume - scale effect - as well as in depicting the environment and construction conditions of the concrete at the construction site.
The performance of specific tests to determine drying shrinkage becomes even more delicate since in the early ages after test specimen casting, shrinkage is sensitive to several parameters, among which is the 28-day curing period immersed in a solution of lime-saturated water, as proposed by the ASTM and ABNT[1] standards, for instance. In addition to requiring a relatively long period for execution – which depending on the speed of strain stabilization can take up to several months - such test readings may not always feature the same sensitivity towards strain variation in time, leading to potential distortions in the results.
Another great concern regarding the execution of the drying shrinkage test has to do with the moment between the moist curing just after the casting of the test specimen and when it is taken to the container with lime water, which requires a period of 24 hours. For high strength concretes (HSC) this phase may distort the drying shrinkage results, since the autogenous shrinkage in the early ages is quite severe in this concrete and it is not taken into account in the test results [2].
In short, in this study autogenous and drying shrinkage tests were performed on a HSC, based on a Brazilian test procedure[2], similar to the one proposed by the American standard[3]. In the shrinkage test, specimens were immersed for 28 days in lime water, and the procedure was started straight after the readings were taken. Test specimens were also used at the age of one day as the start of readings for strain, given the potential shrinkage of concrete. With the results obtained, the process of comparing values generated by the tests can identified possible improvements in the standard procedures which may be more compatible with the real situation of concrete.
It is important to highlight that the pilot tests presented in this paper aim to contribute in a concise way to the subject, so that future research studies may further corroborate the propositions advanced herein.

2 EXPERIMENTAL PROGRAM

2.1 Materials and Mixture Proportions

As this study had no intention of varying material proportions in the concrete, a single mixture proportion of HSC was stipulated as shown in Table 1. Coarse aggregate of a maximum diameter equal to 9.5 mm and artificial sand were used, both originating from a quarry of granite rock. The addition of silica fume was contemplated, in replacement for cement in the concrete, in the proportion of 10% in volume. The portland cement employed was of a high early strength. Due to the use of a superplasticizing admixture, the W/C achieved was 0.235 with slump surrounding 80 mm. As a result for this concrete, a specific gravity of 2336 kg/m^3 was achieved, with a total of 2.9% of entrained air.

2.2 Test Specimens and Test Procedures

Six prismatic test specimens measuring 100x100x300 (mm) were cast for the shrinkage tests. After casting they were all kept in a moist room with humidity above 95% and temperature around 23 °C for the first 24 hours. After this phase, the

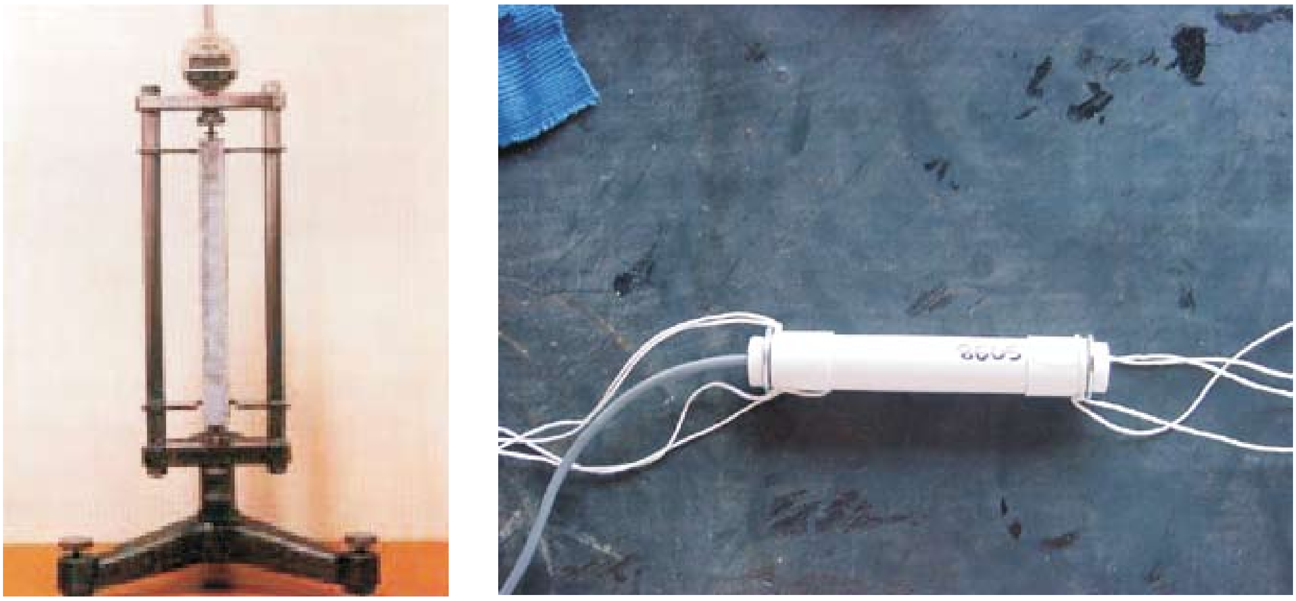
Figure 1 – (a) Test specimens sealed with paraffin for the autogenous shrinkage test (b) Test specimens for the drying shrinkage test

(a)

(b)

[1] *ASTM: American Standard Test Materials. ABNT: Associação Brasileira de Normas Técnicas (Brazilian Standard).*
[2] *NM131 (Mercosur Standard): Hardened concrete – Determination by drying shrinkage.*
[3] *ASTM C157: Standard Test Method for Length Change of Hardened Cement Mortar and Concrete.*

Figure 2 – (a) Apparatus for strain readings by mechanical strain meter (b) Electric Carlson strain meter, in detail, to be embed in test specimen



(a) (b)

test specimens were each allocated to their specific purposes: the pair used in the autogenous shrinkage test was waterproofed with paraffin to avoid water loss to the environment, a pair was left in lime water immersion for 28 days for the subsequent drying shrinkage test, and the other pair did not undergo immersion in the solution and was taken straight to the test in an environment of humidity around 50% and average temperature of 23°C, to determine the so-called potential or total shrinkage (Fig. 1). Six other cylindrical test specimens measuring 150x300 (mm) were also used to determine compressive strength at three different ages of analysis.

Table 1 – Data for high strength concrete in fresh state

Equivalent cement	kg/m³	688
Cement		619
Silica fume		50
Water		162
Natural sand		427
9.5 mm crushed aggregate		1081
Superplasticizing admixture		17.2
W/C		0.235
Slump test (mm)		80
Entrained air (%)		2.9
Specific gravity (kg/m³)		2336

The reading procedures for strains due to drying shrinkage were based on the mechanical process, in which pins were installed before casting on the ends of the longitudinal axis of the test specimens for subsequent readings by means of an external mechanical strain meter. Another reading procedure adopted involved using a Carlson electric strain meter embedded in the concrete before casting the test specimens (Fig. 2).

3 TEST RESULTS

It is important to note that the positive convention adopted for strains is equivalent to concrete shrinkage while, by the same token, negative strain reflects an expansion process in the test specimen.

3.1 Evolution of Compressive Strength with Age

To verify the evolution of compressive strength resulting from concrete aging, strength results were determined for the ages of 6, 21 and 28 days. The highest value reached at the age of 28 days was approximately 85 MPa. Fig. 3 shows the estimated evolution of compressive strength based on the test results. It can be noted therein that the highest strengths are reached in the early ages, and for those around 28 days, there is a virtual stabilization of the results.

3.2 Autogenous Shrinkage

The autogenous shrinkage test was performed with the primary aim of correcting the results for total shrinkage

Figure 3 – Evolution of compressive strength and loading age

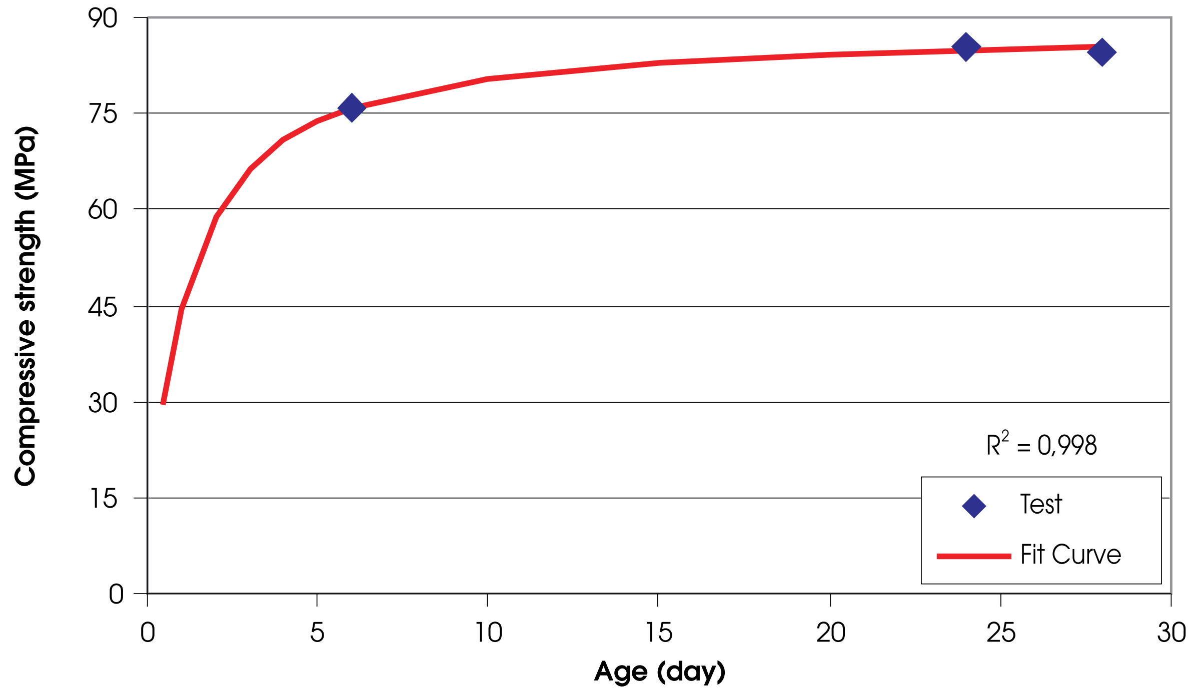


Figure 4 – Test results for autogenous shrinkage and time

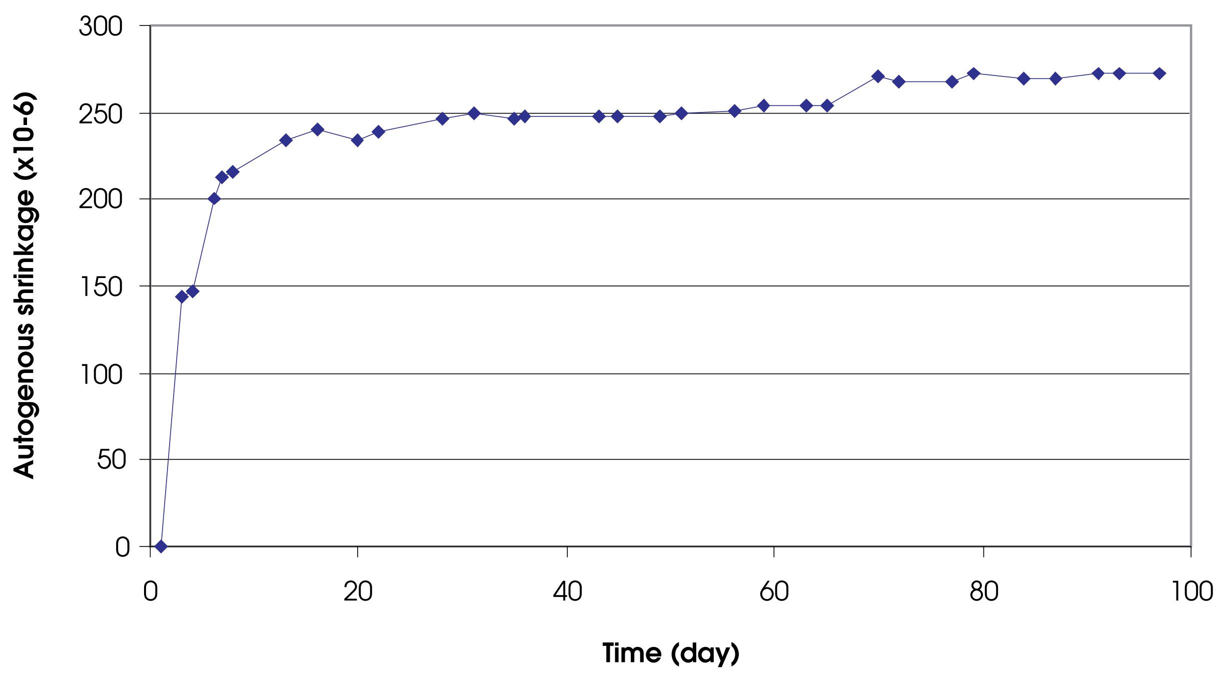


Figure 5 – Total shrinkage achieved in test by means of electric and mechanical strain meter, without immersion in lime water

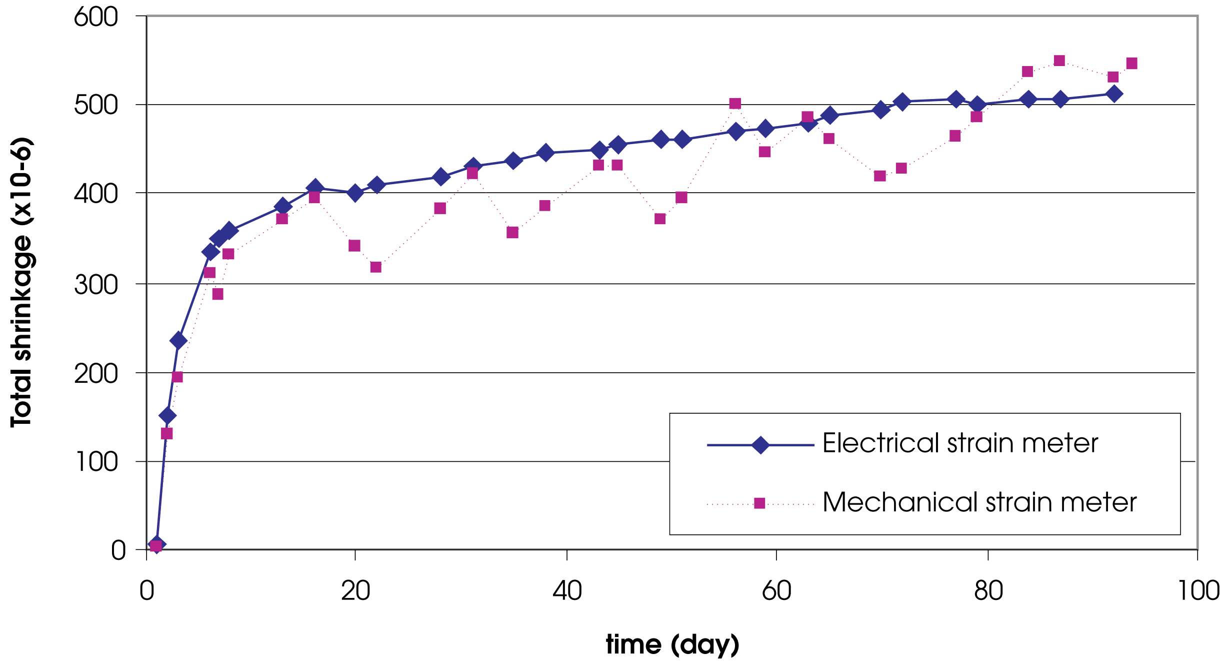


Figure 6 – Drying shrinkage achieved in test by means of electric and mechanical strain meters, with lime water immersion for 28 days (ASTM C157)

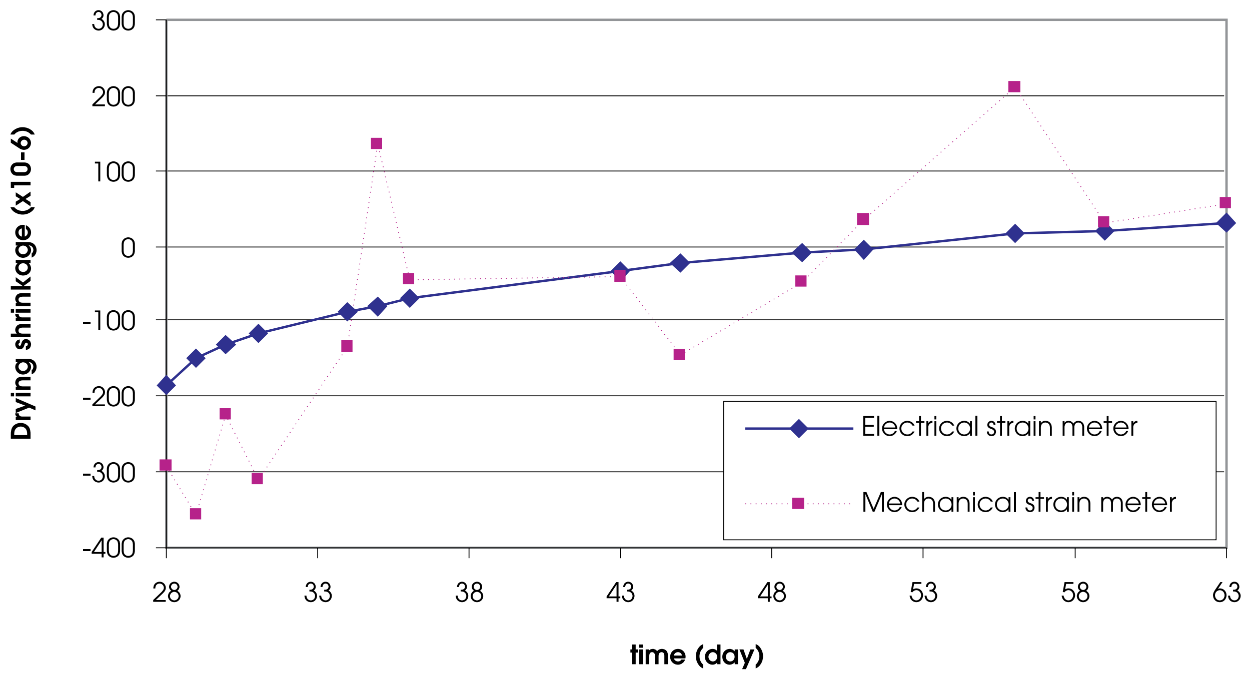
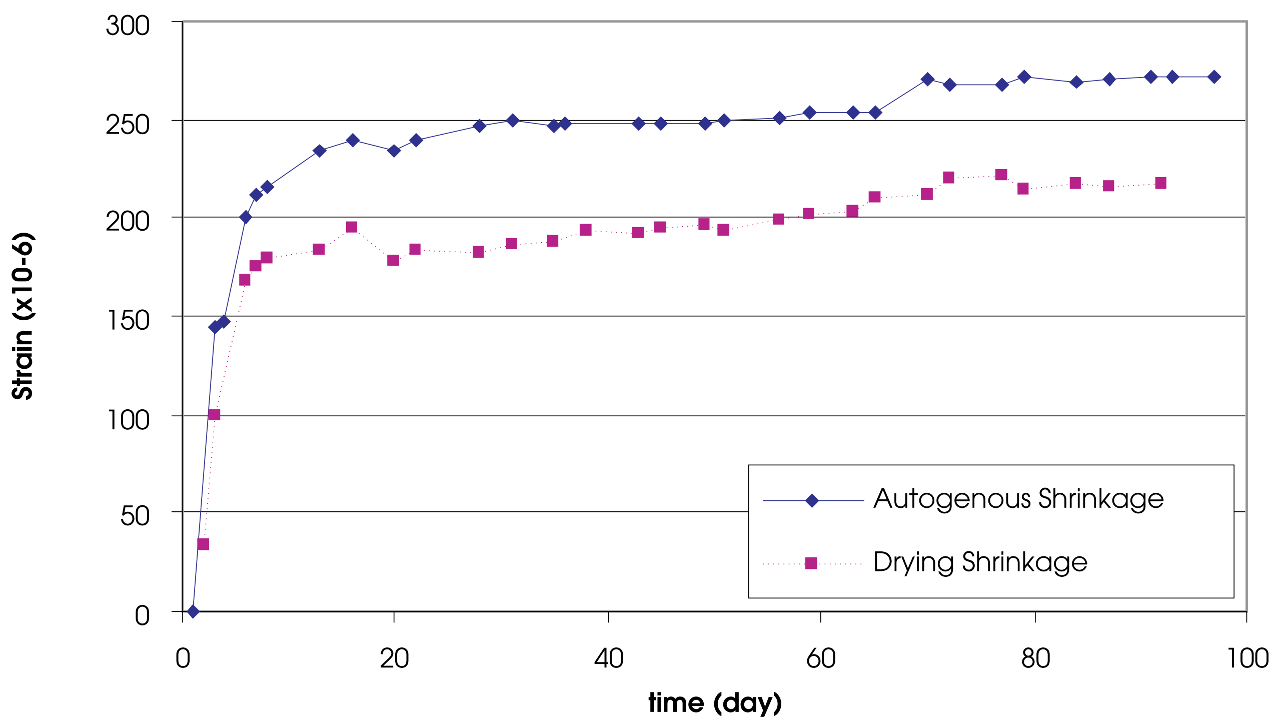


Figure 7 – Comparison between drying and autogenous shrinkages



in the test specimens submitted to drying since the early days of the test.

In this test, only strain readings by means of the embedded strain meter were taken. The last readings before this paper was produced were taken at 97 days and were equal to $270x10^{-6}$. It can be noted by the graph in Fig. 4 that there is a sharp growth in strains in the early ages, which proves that autogenous shrinkage is more intense for HSC, including at the early ages [3]. It can also be noted by Fig. 4 that after 28 days of testing, autogenous shrinkage virtually stabilized, bringing the test to an end for the lack of any practical purposes for its continuation.

3.3 Total and Drying Shrinkage

The results for the shrinkage test since the early ages, after the concrete test specimens were cast, reached strains of $520x10^{-6}$ at 97 days of testing (Fig. 5). For the test specimens immersed in water with lime for 28 days it can be noted by the graph in Fig. 6 that, as expected, there is a negative strain which, according to the convention adopted in this paper, is equivalent to an expansion of $200x10^{-6}$ determined by Carlson strain meter, there occurring subsequently an additional total shrinkage increase of $50x10^{-6}$, due to the effect of drying outside the submersed environment. It must however be noted that in relative terms, that same shrinkage strain relating to the initial value was $250x10^{-6}$.

Figs. 5, 6 respectively show the evolution of shrinkage strains in the tests without and with curing in lime water immersion. These figures also show the values for shrinkage straining obtained by the readings on the mechanical and electric strain meters. According to the Concrete Laboratory of Furnas Centrais Elétricas S. A. – Brazil [4], the electric strain meter is of higher precision, but it is noted that the values reached by means of the mechanical strain meter, despite some oscillation, provided results similar to those of the electric apparatus at a lower cost.

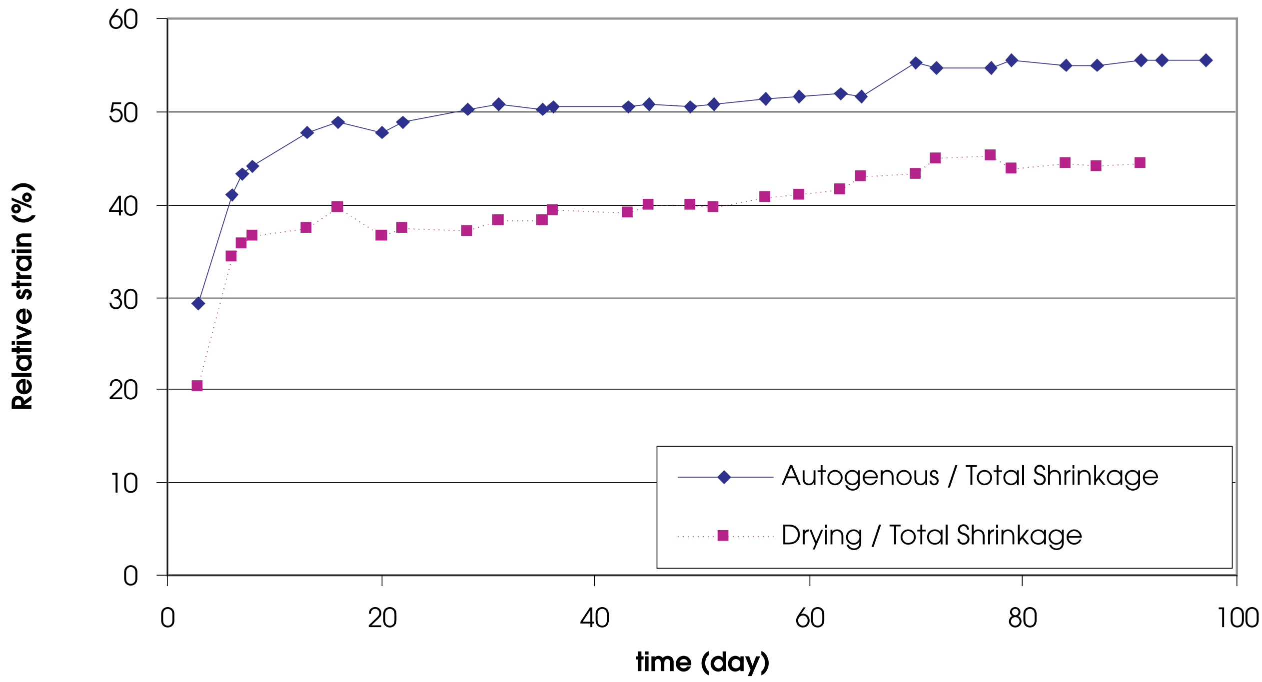
It can be deduced from the shrinkage test (Fig. 6) that the autogenous shrinkage was virtually cancelled due to the immersion in lime water for 28 days, thus allowing one to assume that the measured shrinkage refers only to the effect of external drying after the immersion period. In Fig. 5, however, the effect of autogenous and drying shrinkage were eminent due to the direct exposure to drying at the early ages, and it can be stated that the readings for the strain values encompass both shrinkage effects (total shrinkage).

4 DISCUSSION OF RESULTS

4.1 Comparison Between Autogenous and Drying Shrinkage

As expected, Fig. 7 shows that autogenous shrinkage for the

Figure 8 – Autogenous and drying shrinkages for total shrinkage against time

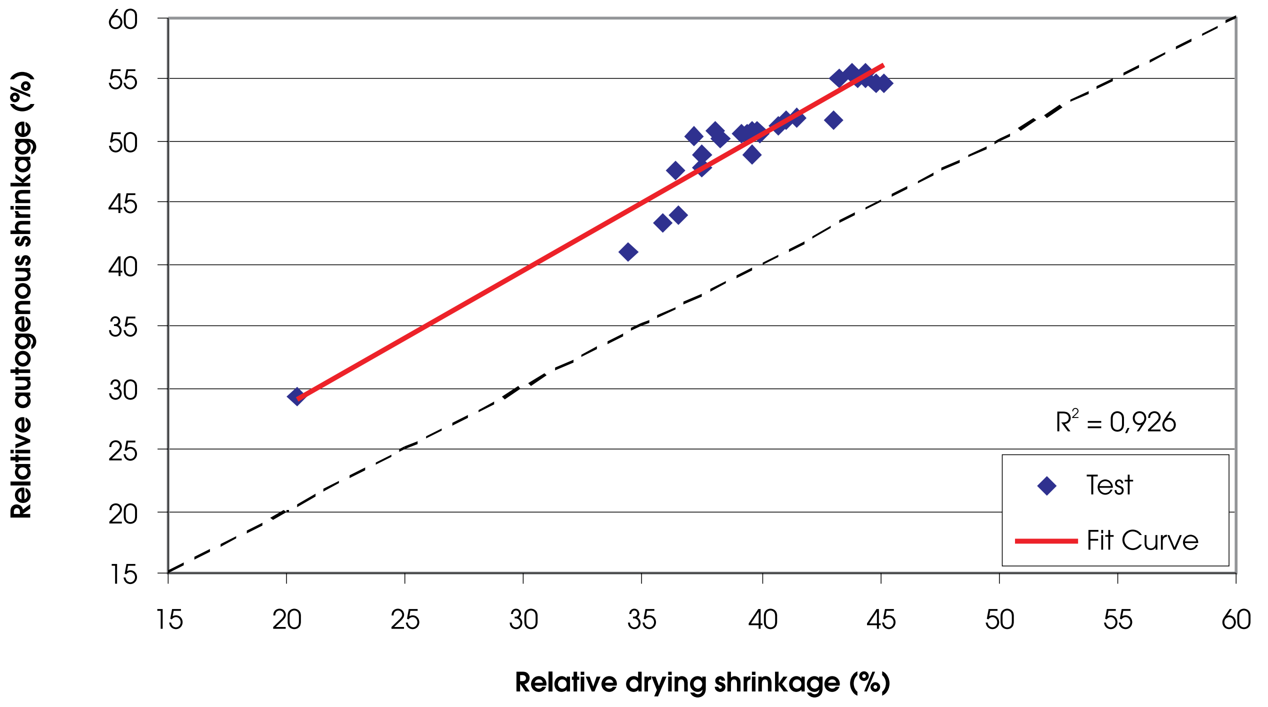


HSC features higher strain values than drying shrinkage. It is important to highlight that the results for drying shrinkage displayed in the graph in Fig. 7 were achieved according to values for the total shrinkage test (Fig. 5) minus the values for the autogenous shrinkage test (Fig. 4). The drying shrinkage in this test was approximately 80% of autogenous shrinkage at 93 days. Studies conducted by Yang et al [5] show that the proportion between the shrinkages is equal to 70%, for a concrete of 120 MPa in compressive strength and a W/C of 0.25. For practical purposes in HSC engineering, these propositions allow a preliminary estimate for drying shrinkage by performing only autogenous shrinkage.
Fig. 8 shows the behavior with the test time for autogenous shrinkage and drying shrinkage in comparison to total final shrinkage at 93 days. It is noted that the contribution of autogenous shrinkage in total shrinkage is greater at all times during the test, especially from the 16th day onwards, when the difference in percentage is approximately 10% for drying shrinkage. Still in Fig. 8, it is noted that autogenous shrinkage at 3 days corresponds to 30% of total shrinkage. A similar value was found by Altoubat and Lange [6] for a conventional concrete.
Fig. 9 features a comparison between drying and autogenous shrinkages with respect to total shrinkage. The dotted diagonal line represents a hypothetical equal relation between the autogenous shrinkage and the drying shrinkage, that is, the respective shrinkages would increase proportionally at a 1:1 ratio. The line adjusted according to the test results (continuous line) shows that its inclination is almost the same as the one in the hypothetical diagonal line, although displaced approximately 10% upwards. This proves that autogenous shrinkage is greater than drying shrinkage in approximately 10% for this case study. Yet, its evolution with time remain constant.

4.2 Comparison Between Drying Shrinkage Tests

The shrinkage measured in the tests from the early ages, without immersion in lime water, represents the situation of a potential shrinkage strain (total shrinkage) in a concrete region close to the surface of a recently concreted structure without an effective cure. By subtracting the autogenous shrinkage from the result for this test, it can be considered that the resulting strain refers to the drying shrinkage. Fig. 10 therefore shows the results for drying shrinkage over time, calculated as described above, and the values achieved for drying shrinkage performed in compliance with ASTM C157 (similar to NM131).
It is noticed in Fig. 10 that the drying shrinkage results obtained by the immersion in lime water test were higher than the results obtained for drying shrinkage reached indirectly without immersion. This can indicate a probable late effect of the autogenous shrinkage in the drying shrinkage test standardized by ASTM C157. In this figure, it can also be preliminary assumed that for a HSC structure (even one featuring efficient curing with water film enveloping the concrete) drying shrinkage will reach values higher than no-cure situation. However it is important to stress that autogenous shrinkage is severe to HSC

Figure 9 – Comparison between drying and autogenous shrinkage in relation to total shrinkage



and that an effective immersion cure would reduce the value for total shrinkage in at least 55%, according to this study's test results for the analyzed concrete (see Fig. 8).
Finally, it is important to highlight that in all the shrinkage tests performed the effect of autogenous shrinkage in the initial 24 hours was not considered due to difficulties in handling the test specimens, which enables one to conclude that the values found for autogenous shrinkage in the tests are possibly higher and so are, therefore, the results for total shrinkage.

5 FINAL COMMENTS

In the results for the pilot tests conducted to determine autogenous shrinkage and drying shrinkage in HSC, the following facts may be observed:

a. The results for autogenous shrinkage show the real importance of this strain, by exceeding the results for drying shrinkage that are more sensitive in conventional concretes. It must be stressed that, unlike drying shrinkage, the autogenous strain variation can only be combated with efficient curing, by means of constant and uninterrupted moistening for a long period after placing, although in practical terms such control is difficult to accomplish;
b. According to Fig. 4, autogenous shrinkage proved more intense in the first ten days after the test specimens were cast;
c. In Fig. 5, 6, it was verified that the mechanical strain meter, despite variations in the readings, produced results that are compatible with those provided by the electric strain meters;
d. Similarly to what Han and Walraven [3] verified, this study demonstrated that total shrinkage in test specimens submitted to drying in the early ages is more than double the value of shrinkage strain if the cure is effected until the age of 28 days;
e. Regarding total shrinkage, autogenous shrinkage produced a strain result 10% higher than that for drying shrinkage;
f. The results obtained in the shrinkage test on specimens exposed to drying from the early ages, after the results for autogenous shrinkage obtained in a specific test were deducted, yielded values lower than results for the drying shrinkage test at the approximate time of 92 days (Fig. 10);

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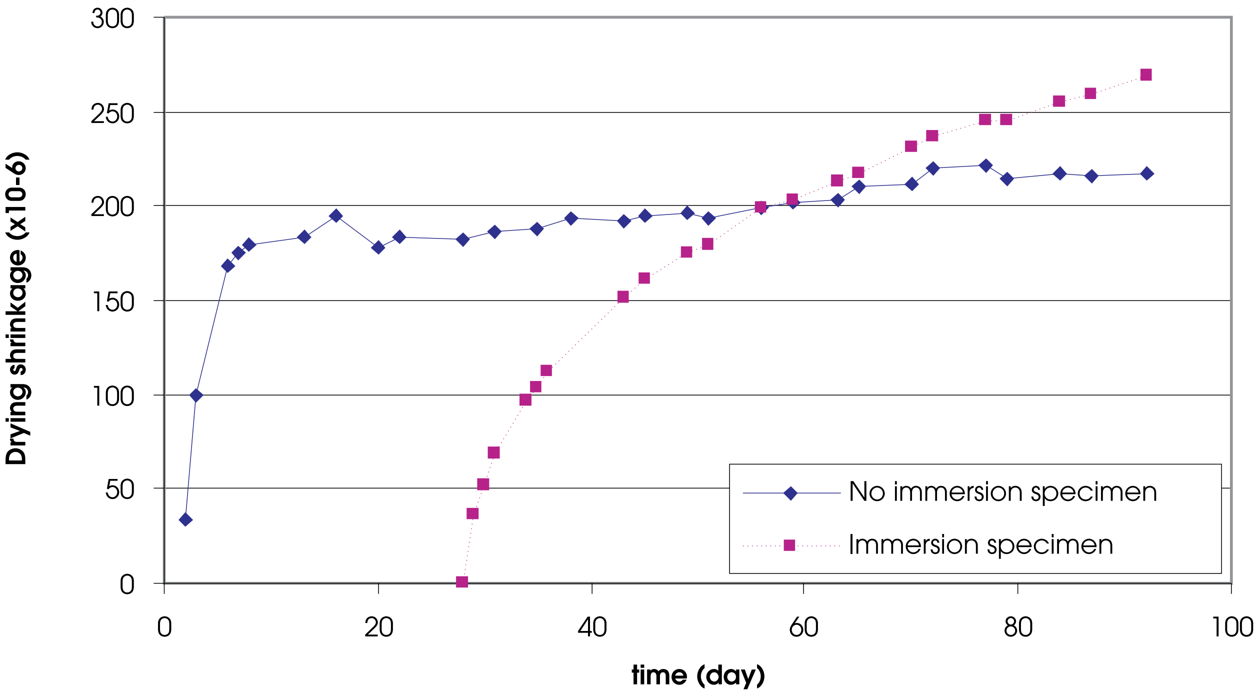
Figure 10 – Drying shrinkage achieved in test with lime water immersion (ASTM C157) and without immersion, achieved since the early ages



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